ARTICLES

A comparison of three oral electrolyte solutions in the treatment of diarrheic calves

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Abstract

Thirty-six diarrheic calves infected with rota- and coronaviruses were randomly allocated to one of three oral electrolyte treatments: Ion-Aid (Syntex Agribusiness), Life-Guard (Norden Inc), or Revibe (Langford Inc). The calves were also allowed voluntary access to milk which was offered at the rate of 5% of body weight per feeding in two feedings daily. There were significant differences in recovery rate among calves treated with the different electrolytes. Only 33% of Ion-Aid-treated calves recovered; Revibe- and Life-Guard-treated calves had high recovery rates of 92% and 83%, respectively. The much higher recovery rates with Life-Guard and Revibe were attributed to the presence of an alkalizing agent in these preparations. Life-Guard uses bicarbonate to counteract acidosis and there was some evidence that this may have interfered with milk digestion. Revibe uses acetate; this was effectively metabolized within the calves' tissues and produced alkalization without interference with milk digestion.

Résumé

Comparaison entre trois solutés d'électrolytes administrés par voie orale pour le traitement de la diarrhée chez le veau

Trente-six veaux diarrhéiques infectés de virus rota et corona furent assignés au hasard à l'un des trois groupes de traitements, par voie orale, de solutés à base d'électrolytes : Ion-Aid (Syntex Agribusiness), Life-Guard (Norden Inc.) ou Revibe (Langford Inc.). Les veaux avaient aussi accès à du lait sur une base volontaire, deux fois par jour, à raison de 5 % de leur poids corporel. Les résultats indiquèrent une différence significative quant au taux de rétablissement des veaux selon le type de traitement. Trente-trois pour cent des veaux traités avec Ion-Aid se sont rétablis alors que les veaux traités avec Revibe et Life-Guard ont démontré un taux de survie de 92 et 83 % respectivement. Le taux de rétablissement plus élevé avec l'utilisation de Life-Guard et Revibe fut attribué à la présence d'un agent alcalinisant dans ces préparations. Life-Guard utilise du bicarbonate pour neutraliser l'acidose ce qui pourrait interférer avec la digestion du lait. Revibe, par contre, contient un acétate qui est métabolisé efficacement par les tissus et produit une alcalinisation, sans interférer avec la digestion du lait.

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Introduction

Oral electrolyte solutions have become a standard part of the treatment of diarrheic calves over the last two decades. Several studies attest to the usefulness of the combination of milk withdrawal and electrolyte feeding in reducing mortality from diarrhea in calves (1-3).

The initial aim of oral electrolyte therapy was to correct dehydration by providing water and salt together with glucose and glycine to facilitate sodium absorption (4-6). Other substances have also been added to help maintain homeostasis. Potassium salts were added to compensate for potassium losses (6-8). Bicarbonate, acetate, or citrate were incorporated to counteract acidosis (9). Acetate, citrate, and citric acid were added to further improve water and electrolyte absorption (2,10). A wide range of electrolyte products has come into use and it is difficult to discriminate among these alternatives because of a dearth of studies on the comparative efficacy of the products.

Manufacturers of commercial electrolyte preparations take different approaches to the need to counteract acidosis in diarrheic calves. Some preparations, such as Ion-Aid (Syntex Agribusiness, Mississauga, Ontario), contain no alkalizing agent and in fact have a mild acidifying action when fed to normal calves (9). This approach relies on the kidneys to compensate for acidosis. However, studies of intravenous fluid therapy indicate that severely acidotic calves are unable to correct their acidosis even if hydration is restored (11). Studies using oral electrolytes in experimentally induced diarrhea in calves also indicated that the absence of an alkalizing agent prevented the correction of acidosis and reduced long-term survival (3). Bicarbonate is used as an alkalizing agent in some oral electrolyte solutions and it has the advantage of being effective immediately. Disadvantages include neutral-

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ization of abomasal acidity, and impairment of milk clotting, milk digestion, and growth of the calf (12). An alternative approach to alkalizing therapy has been to use metabolizable bases such as acetate or citrate. These products are only effective when they are metabolized within the liver and other tissues (13). Thus they do not interfere with abomasal acidity and should not affect milk clotting or digestion. A potential disadvantage is that metabolism of these bases may be impaired in severe shock, limiting their efficacy (11).

The objective of this study was to compare the efficacy of three commercial oral electrolyte compounds in treating diarrheic calves. Ion-Aid was chosen as an example of a product that contained no alkalizing agent. Thus it would be expected to perform poorly in maintaining normal acid base status. Life-Guard (Norden Inc., Mississauga, Ontario) was chosen as an example of a bicarbonate-containing electrolyte preparation. It was expected to give good maintenance of acid-base balance, but be less successful in maintaining normal milk digestion. Revibe (Langford Inc., Guelph, Ontario) is a new product. It contains similar amounts of alkalizing agent to Life-Guard but uses a metabolizable base, acetate, instead of bicarbonate. We wished to see if this product would allow maintenance of acid-base status together with milk digestion. The electrolytes were compared in calves with viral diarrhea. All calves were offered milk throughout the trial. The continued availability of milk mimics the situation found on beef farms where calves are treated while continuing to nurse the cow.

Materials and methods

Inoculum

This was initially collected from three diarrheic calves from one farm presented to the Large Animal Clinic, Western College of Veterinary Medicine, for the treatment of severe acidosis and dehydration. Fecal material was collected, pooled, and frozen at −70°C in individual 10 mL aliquots. The feces were positive by fluorescent antibody tests for rota- and coronaviruses. Electron microscopy confirmed the presence of these viruses (14) and failed to provide evidence of the presence of any other known viral pathogen. Bacteriological cultures were negative for enterotoxigenic, K99 positive, *Escherichia coli* and for the presence of *Salmonella* species. Cryptosporidia were present on fecal flotation but these are believed to be killed by freezing (15).

Calves

Holstein calves were purchased from either local farmers or a local auction market. The calves were selected with the objective of being approximately three to nine days old on the day of inoculation. The calves were cared for in accordance with the guidelines for the care and use of experimental animals published by the Canadian Council on Animal Care. On arrival at approximately 1400 hours all calves were fed 2 L of Revibe followed by 2.5 L of whole cows' milk at 1700 hours. The following day the calves were offered two feedings of milk at the rate of 5% of body weight per feeding, and were weighed three times. Their general health was assessed in the morning and afternoon. At the afternoon feeding, 10 mL of inoculum was incorporated into the milk meal.

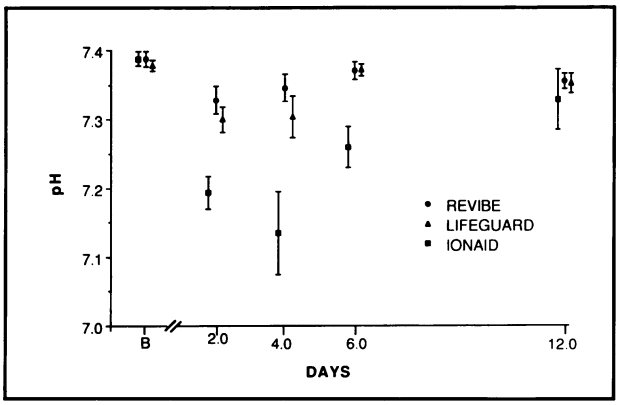

Figure 1. Venous blood pH (mean ± 1 SEM) versus time in days. B on the time axis indicates the baseline day. There were 12 observations per treatment group at all time periods with the following exceptions: Ion-Aid, day 2, n = 11; day 3, n = 9; day 4, n = 7; day 5, n = 6; days 6–12, n = 4; Life-Guard, days 5–12, n = 10; Revibe, days 7–12, n = 11.

A total of 42 calves was purchased. Two were excluded from the trial because they were not healthy at the initial examination. Forty calves were inoculated; 36 developed diarrhea between one and six days after inoculation and entered the trial.

Time measurement

The day after arrival, when the calves were healthy and were weighed, was designated the baseline day. The calves were then weighed every two days and clinically assessed twice daily until they became diarrheic. The last weight when the calf was clinically healthy was used as the initial weight of the calf. The first morning on which diarrhea was observed (fecal score > 2, see below for details of scoring system) was called day 1 and the days were numbered consecutively from this time. The experiment terminated on day 12. Weighing was carried out every two days starting at day 2. Venous blood was collected anaerobically for blood gas and packed cell volume measurements on the baseline day and days 2, 4, 6 and 12. Fecal samples were collected at the same time periods. Time ranges used in this paper are inclusive.

Assessment

The calves were weighed three times daily: before the morning feeding at 0800 hours, at 1200 hours, and before the afternoon feeding at 1600 hours. The mean of these weights was recorded as the daily weight. Rectal temperatures were measured once daily. Clinical assessment of each calf's alertness, hydration status, and severity of diarrhea was performed using a scoring system described previously (12), with the exceptions that warmth of the extremities and volume of feces were not quantitated. Fecal scores were graded from 0 in calves with firm, formed feces to 3 in calves with watery diarrhea. The scores for enophthalmia and skin tenting were summed to give the hydration score. This was graded from 0 in well hydrated calves to 4 in severely dehydrated calves. The individual scores for

Table 1. Composition of oral electrolytes given to calves with diarrhea

	Ion-Aid	Life-Guard	Revibe
Sodium, mmol/L	76	113	120
Potassium, mmol/L	17	26	20
Chloride, mmol/L	78	51	50
Bicarbonate, mmol/L	0	80	0
Acetate, mmol/L	0	0	80
Glucose, mmol/L	117	166	120
Glycine, mmmol/L	107	36	40
pH	4.9	7.3	6.0

Electrolyte concentrations are based on product information; pH values were measured

menace response, ability to stand, strength of sucking reflex, and tactile response were also totalled to give an overall score for demeanor. This varied from 0 in normal calves to 9 in comatose calves. Assessment was carried out at 0800 and 1600 hours by two clinicians who had no knowledge of the treatment each calf was receiving.

Calves were removed from the experiment and recorded as therapeutic failures if at any time they failed to remain standing following assistance in rising, if they became hypothermic with a temperature $<38°C$, or if they showed evidence of persistent dehydration with a score >3 for more than 24 hours. These decisions were made without knowledge of the electrolyte treatment group.

Laboratory measurements

Fecal pH was measured using a pH meter (Orion Research, Digital Ionalyzer/501, Orion Research Inc., Cambridge, Massachusetts, USA) after the feces had stood for one hour. The electrode was immersed in the feces for five minutes and the pH read.

Packed cell volume measurements were made on heparinized blood after centrifuging the sample in a microhematocrit centrifuge (Damon IEC MB Centrifuge, Damon/IEC Division, Needham Hts, Massachusetts, USA) for five minutes. Samples were measured in duplicate and the assay was repeated if the duplicates varied by more than 0.01 L/L. Blood gas measurements were performed on blood collected anaerobically and stored on ice. All measurements were made within four hours of collection using an automated instrument (ABL 330, Radiometer, Copenhagen, Denmark).

Design

Diarrheic calves were allocated to groups of three on the basis of similar weights and each calf was randomly assigned to one of three electrolyte therapies: Ion-Aid (Syntex Agribusiness), Life-Guard (Norden Inc) or Revibe (Langford Inc).

Oral electrolytes were offered during the diarrheic period in accordance with the manufacturers' instructions: Ion-Aid was fed at the rate of 2.25 L per feeding, Revibe and Life-Guard at 2 L per feeding. If the calf refused to drink the electrolyte solution it was tube fed using an ororumenal tube. Oral electrolytes were given twice daily from days 1–4 inclusive of the diarrheic period and once daily from days 5–8. Milk was offered twice daily at the rate of 5% of body weight throughout the trial; milk intake was limited to the amount that was voluntarily consumed in a 15 minute period from a nipple pail. Calves which did not voluntarily consume all their ration from the nipple pail were then encouraged to suck the milk from a nipple bottle for a further 15 minutes. At the end of this period, undrunk milk was measured and discarded. Daily milk intake was calculated as a percentage of the amount offered.

This plan was modified if extra electrolyte feedings were thought to be necessary for a calf's well being. The modifications were that calves that were markedly dehydrated with a combined score for enophthalmia and skin tenting >2.5 were given four feedings of oral electrolytes and no milk that day. On days 4–8, calves that had fecal scores ≥ 2 were given an additional feeding of electrolytes. Between days 9 and 12 calves that were still scouring and had fecal scores >1 were given one feeding of electrolytes per day. Calves that drank <0.5 L of milk at a feeding were also given an extra feeding of electrolytes.

All calves were treated with a potentiated sulfonamide containing 40 mg trimethoprim and 200 mg sulfadoxine per mL (Borgal, Hoechst, Montreal, Quebec) at 3 mL per 45 kg body weight subcutaneously for days 1–6 of the diarrheic period.

The experiment was run in three blocks of twelve calves each (four calves per treatment). In block 1, the first (0900 hours) and third feeding (1600 hours) of the day were milk; electrolytes were given at the second (1300 hours) and fourth (2000 hours) feedings. In block 2, the order of the feedings was reversed. In block 3 the order of the feedings was as for block 1 but additional electrolytes were not given if the calf drank <0.5 L of milk.

Intravenous fluid therapy

Calves that were removed from the oral electrolyte trial were either euthanized or treated with intravenous fluids. Intravenous fluid therapy was carried out in accordance with standard methods (16). Calves that were acidotic were infused with intravenous isotonic sodium bicarbonate. The amount required was calcu-

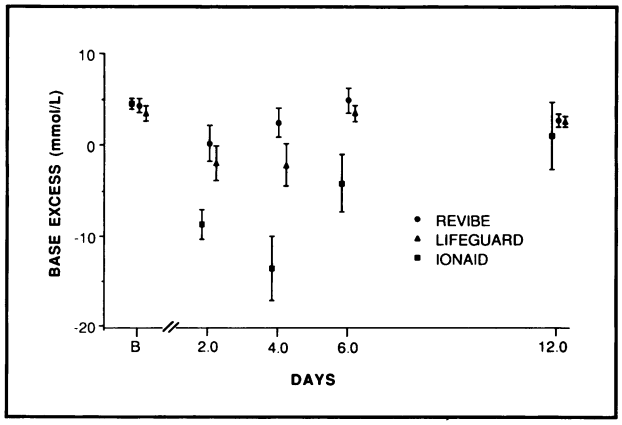

Figure 2. Venous blood base excess, mmol/L (mean ± 1 SEM) versus time in days. See Figure 1 for details of numbers of calves.

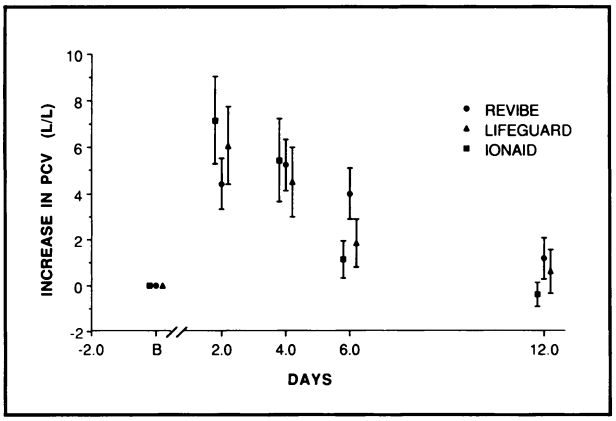

Figure 3. Change in packed cell volume (PCV), L/L (mean ± 1 SEM) versus time in days. See Figure 1 for details of numbers of calves.

lated by multiplying the base deficit by half the body weight in kg. The sodium bicarbonate was mixed with isotonic saline and the fluids were warmed as they were administered. Sufficient total volume was given to correct the dehydration. The calves then usually received at least a further 3.6 L of lactated Ringer's solution. Intravenous fluid therapy was continued until the calf was standing, able to suck, and had a rectal temperature >38.5°C. The calves were then continued on the same protocol as the experimental calves except that all calves were switched to Revibe therapy. Calves which were alkalotic when they were withdrawn from the experiment were rehydrated with intravenous saline and then continued on Ion-Aid therapy. All calves were treated for at least 12 days from the first day of diarrhea. Calves were euthanized if they failed to respond to this therapy as evidenced by persistent diarrhea, the recurrence of weakness, or the development of septicemia.

Statistical Analysis

Data were analyzed on a microcomputer using Systat and Sygraph (17,18). Initially, the 12-day survival rate was compared between electrolyte solutions using chi-square analysis.

Only four Ion-Aid-treated calves completed the experiment and so comparisons of the clinical, body weight, and laboratory findings for the whole period were only made between Life-Guard- and Revibe-treated calves. Baseline body weight, blood gas values, fecal pH, and changes in packed cell volume data were initially compared using a one-way analysis of variance. There were no significant differences between the groups in baseline values (p values >0.2 for weight, blood pH, and base excess variables, p=0.14 for fecal pH). Repeated measures analyses of variance were then performed to compare all values for blood gas, fecal pH, and change in body weight and PCV. This analysis generates both univariate and multivariate repeated measures probabilities. Usually these were similar with the univariate probability smaller (more significant) than the multivariate. When only one probability value is reported for a treatment effect, this is the multivariate value. Both values are given when there are discrepancies between the two values.

Separate analyses of variance were performed for the day 2 blood gas and change in PCV values. A complete data set for all calves was available on this day enabling a comparison of all three electrolytes. If a significant overall difference existed then a planned contrast of the Ion-Aid values against the combined Life-Guard and Revibe values was performed.

Following completion of the analyses of variance, residuals were calculated and normal probability plots made to determine if the residuals followed a normal distribution. The residuals from the milk intake data showed obvious ceiling effects and were not normally distributed. Therefore, the data were reanalyzed using the Mann-Whitney U test. The residuals from all other analyses followed an approximately normal distribution.

Categorical variables for the clinical severity of dehydration, depression, and fecal consistency were compared among the three electrolytes on the baseline day and day 2 using the Kruskal-Wallis test. From days 3–12, only the Life-Guard and Revibe values were compared using the Mann-Whitney U test.

The frequency of the need for the tube feeding of electrolytes was computed for each calf for days 1–4 and days 5–8. The need for additional electrolyte feeding as a result of dehydration, persistent diarrhea, or anorexia was compared using chi-square analysis. The number of additional feedings of electrolytes was computed for days 1–4, 5–8 and 9–12. The values were compared using a repeated measures analysis of variance.

Results

All of the calves had normal feces at the start of the trial. Diarrhea was most severe on day 2 when almost all calves had copious, watery feces and the mean fecal score for each group was 2.6. Fecal scores were very similar on day 3. Scores then declined progressively and on days 7–12 mean scores for each group were always less than 1.6. On day 12, 17 of the 25 calves still on trial had normal feces. There was no significant difference in fecal consistency among the three electrolyte treatments on the baseline day and days 1 to 3 (all p values >0.5) or between Life-Guard and Revibe treatments on days 4 to 12 (p values >0.3 for days 4 to 11 and p=0.11 on day 12). Fecal samples

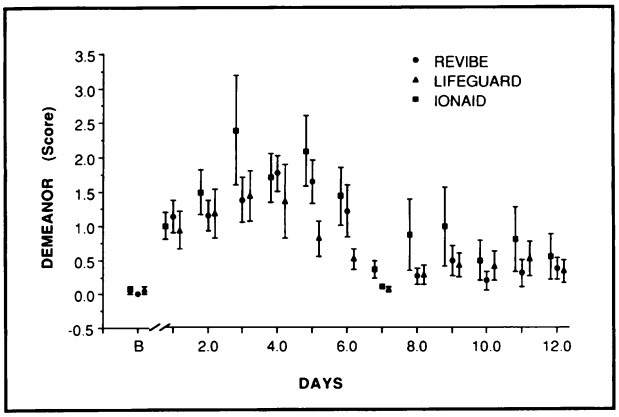

Figure 4. Demeanor scores (mean ± 1 SEM) versus time in days. A normal alert calf has a score of 0, a maximally depressed calf a score of 9. See Figure 1 for details of numbers of calves.

Table 2. Status of calves at the time of their removal from the trial

	Treatment		
	Ion-Aid	Life-Guard	Revibe
Number of calves	8	2	1
Rectal temperature, °C	37 ±0.6[a]	37.9[b] 38.3	38.6
Ability to stand, score	1.4 ±0.2	0 1.75	2
Hydration status, score	1.3 ±0.3	3.5 1	2.25
Weight change[c], kg	−1.1 ±0.2	−4.1 −1.3	−2.2
Venous blood pH	6.967 ±0.042	7.189 7.032	7.429
Base excess, mmol/L[d]	−19.6 ±3.4	−10.8 −21.9	19.2

[a]Values are means ± 1 standard error
[b]Values are for individual calves
[c]Weight change was measured as the difference between the last day of weighing and initial weight
[d]Measured on venous blood

were collected from eight calves between days 1 to 6; seven were positive using a fluorescent antibody test for rotavirus and five were positive for coronavirus. One sample was positive on fecal flotation for oocysts of cryptosporidia. No K99 positive *E. coli* or *Salmonella* species were isolated. Fecal samples were collected from three calves between days 9 and 11; viruses or pathogenic bacteria were not identified but two samples were positive for cryptosporidia oocysts.

There was a significant difference ($p < 0.005$) among the three electrolytes in 12 day survival rate. The condition of eight Ion-Aid calves, two Life-Guard calves, and one Revibe calf deteriorated to the extent that they had to be removed from the trial (Table 1). All the calves that survived to 12 days were eventually sold as healthy animals, with the exception of one calf that was euthanized as part of another project.

The Life-Guard and Ion-Aid calves were acidotic whereas the one Revibe calf that failed to respond to therapy was alkalotic at the time of removal from the trial (Table 2).

A significant change in pH ($p = 0.02$) and base excess ($p = 0.001$) occurred with time in the Revibe and Life-Guard groups. There were no significant differences (p values > 0.5) between Life-Guard- and Revibe-treated calves in either blood pH or base excess. On day 2 of the trial, Ion-Aid-treated calves were significantly more acidotic than calves in the other two treatment groups, blood pH was lower ($p < 0.001$), and base excess more negative ($p = 0.002$) (Figures 1 and 2).

Changes in packed cell volume were significantly affected by time in the Revibe and Life-Guard groups ($p = 0.001$), with peak values on day 2. Differences were not found between Life-Guard and Revibe at any time (p values > 0.4) (Figure 3). Changes in PCV were not significantly different among the three electrolyte therapies on day 2 ($p = 0.47$). Dehydration scores varied from 0 in hydrated calves to 4 in maximally dehydrated calves. Baseline values for all calves were 0. Scores peaked on day 3 with mean scores of 1.0, 0.7 and 0.3 in Ion-Aid-, Life-Guard-, and Revibe-treated calves, respectively. Scores then gradually declined and on days 7–12 mean daily scores were < 0.2 in both Revibe and Life-Guard groups. There were no significant differences in scores among the three treatments on the baseline day or days 1 to 2, or between Life-Guard and Revibe on days 3 to 12 (all p values > 0.14).

Overall, the calves were mildly depressed between days 1 and 6 with peak scores on day 4. There were no significant differences among the three treatments on days 0 to 2. There was a tendency for the difference in scores between Life-Guard and Revibe on days 5 and 6 to be significant ($p = 0.08$ and 0.07, respectively) but not at any other time (all p values > 0.16) (Figure 4). The frequency with which the oral electrolyte solutions had to be administered by intubation for Ion-Aid, Life-Guard, and Revibe was 52%, 30% and 40% during days 1 to 4, and 10%, 5% and 19%, respectively, during days 5 to 8. The frequency of intubation with Life-Guard was not significantly different from Revibe ($p = 0.09$).

An initial analysis of variance indicated that milk intake changed in a time-dependent fashion in both Life-Guard- and Revibe-treated calves and that there was no significant difference between the two groups. However, the residuals were not normally distributed. Therefore, the Mann-Whitney U test was employed to examine for treatment effects at each individual time period; significant differences were not found (all p values > 0.2) (Figure 5). The rate of weight gain was affected by time ($p = 0.001$) but was not significantly different between Life-Guard and Revibe therapy ($p = 0.14$) (Figure 6).

There were significant ($p < 0.001$) time-dependent changes in fecal pH in Life-Guard- and Revibe-treated calves. There was a trend for pH to rise throughout the experiment and there appeared to be a particularly sharp increase coincident with the outbreak of diarrhea. Revibe-treated calves had significantly higher (univariate $p = 0.02$, multivariate $p = 0.19$) fecal pH values (Figure 7).

Three Revibe- and two Life-Guard-treated calves had to be given extra feedings of electrolyte solution because they became severely dehydrated; this difference was not significant ($p = 0.66$). Six Revibe and four Life-Guard calves received additional electrolytes because they drank < 0.5 L of milk; this was not statistically significant ($p = 0.12$). Nine Revibe and 10 Life-Guard calves were given additional electrolytes because of continued diarrhea; these frequencies were not statistically different ($p = 0.66$). Revibe-treated

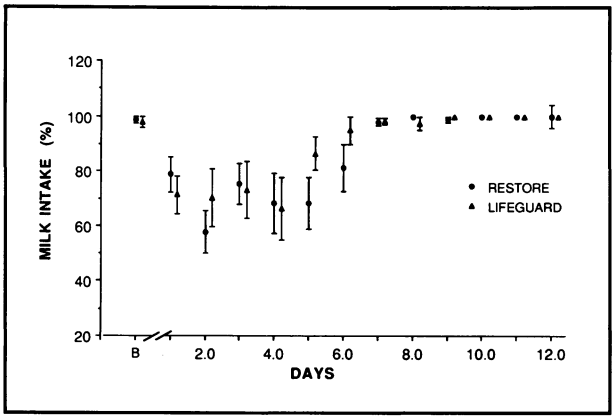

Figure 5. Milk intake (mean ± 1 SEM) as a percentage of the total amount offered versus time in days. B on the time axis indicates the baseline day. There were 12 observations per treatment group at all time periods with the following exceptions: Life-Guard, days 5–12, n = 10. Revibe, days 7–12, n = 11.

calves were given 6.4 ± 1.7 (mean ± SE) extra electrolyte feedings; this was not significantly different ($p > 0.2$) from the 3.7 ± 1.0 additional feedings received by Life-Guard-treated calves.

Of the 11 calves (eight Ion-Aid, two Life-Guard, one Revibe) that were removed from the trial at 3.8 ± 0.4 days from the beginning of diarrhea, five were euthanized immediately. One of these euthanized calves (Ion-Aid treatment group) developed bloody diarrhea prior to euthanasia; at necropsy this calf had a necrotizing enterocolitis with diffuse microthrombosis of the small intestine, this was particularly prominent in the villi.

Six calves withdrawn from the experiment were catheterized and treated with intravenous fluids. Only two of the six calves recovered completely; these calves had initially been on Life-Guard and Revibe therapy. The other four (all from the Ion-Aid treatment group) were euthanized at 15 ± 0.9 days because of chronic diarrhea and weight loss (four calves), which was complicated by septicemia (two calves).

Discussion

We produced neonatal diarrhea in calves by inoculation with rota- and coronaviruses obtained from calves with naturally occurring cases of diarrhea. The calves which provided the inoculum were from a problem herd and the inoculum produced severe diarrhea in most of the experimental calves. The calves were allowed access to milk throughout the experiment and this mimics the situation of many beef farms where diarrheic calves are treated in the field and allowed continued access to their dams.

An important finding was the poor therapeutic success obtained with Ion-Aid. This is probably due to the lack of an alkalizing agent in this product. Over 67% of Ion-Aid calves failed to maintain homeostasis on Ion-Aid therapy and had to be removed from the trial. In field situations this would mean that most of these calves would have died. Our attempts to treat these calves with intravenous fluids were successful in resuscitating the calves but eventually all had to be euthanized because of chronic diarrhea. This occurred despite the fact that Ion-Aid was fed at the manufacturer's recommended levels from the onset of diarrhea. Previous work has shown that omission of an alkalizing agent reduces the efficacy of experimental electrolyte solutions in calves that are allowed to become acidotic before therapy is commenced (3). It is also known that acidosis is likely to be more severe in diarrheic calves older than eight days of age (19,20). In the present trial, Ion-Aid-treated calves became significantly more acidotic than Life-Guard- and Revibe-treated calves, and severe acidosis was present in Ion-Aid-treated calves when they were removed from the experiment. The present study is the first North American demonstration that commercial oral electrolyte solutions which contain no alkalizing agent can give poor therapeutic success, even though they are fed from the first signs of diarrhea. Overall, it seems likely that great care should be exercised when using products that contain no alkalizing agents in calves with severe diarrhea.

Both Life-Guard and Revibe gave very good therapeutic success; 83% of Life-Guard and 92% of Revibe-treated calves survived for 12 days and eventually recovered. This high success rate was probably mainly due to the presence of an alkalizing agent in both products. The amount of alkalizing agent in the two products was identical — 80 mEq/L. Life-Guard contains bicarbonate as the alkalizing agent whereas Revibe contains acetate and also 8 mEq/L of citric acid, an acidifying agent, and thus has a net alkalizing action of 72 mEq/L. Acetate is only effective as an alkalizing agent if it is metabolized within the calf's tissues; in the process, hydrogen ions are removed and water is formed. Studies have shown that acetate is as effective an alkalizing agent as bicarbonate in healthy calves (13). In the present study, acetate metabolism was not impaired in severely diarrheic calves as evidenced by the similar acid-base values in both Life-Guard- and Revibe-treated calves. Studies with diarrheic calves that required intravenous fluid therapy indicated that, although acetate was more effective than lactate in correcting acidosis, it was not as good as bicarbonate (11). The likely reason for the difference in results between this and the present study is that calves requiring intravenous therapy have severely compromised cir-

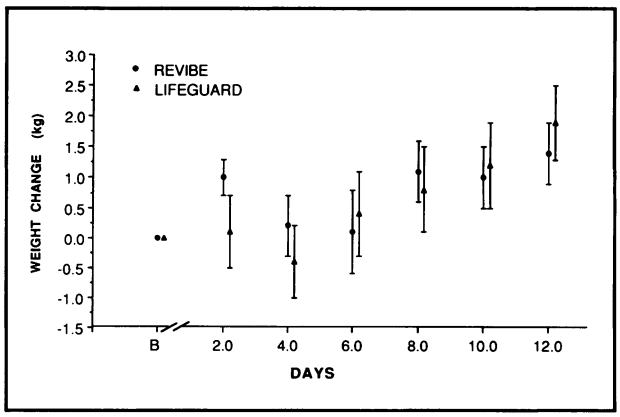

Figure 6. Change in body weight, kg (mean ± 1 SEM) versus time in days. See Figure 5 for details of numbers of calves.

culatory systems and are often in shock. Under these circumstances, cellular metabolism is impaired. In the present study, the calves given oral electrolytes were able to maintain themselves in a better circulatory state and thus cellular metabolism of acetate was unaffected.

Previous work has shown that bicarbonate-containing electrolytes impair weight gain in milk-fed diarrheic calves (12). This is presumably because bicarbonate impairs clotting of milk within the abomasum. In the present study, both Life-Guard and Revibe gave similar weight gains. The major differences between the two studies are that the calves were allowed to voluntarily suck milk from a nipple pail in the present trial, whereas in the previous trial some calves were bucket fed and milk that was not drunk in five minutes was then force-fed by intubation. It is possible that allowing the calves to nurse and the lack of tube feeding in the present study facilitated abomasal clot formation and reduced the inhibitory effects of the bicarbonate in Life-Guard on clotting. However, the lower fecal pH's in Life-Guard-treated calves may mean that more milk was escaping upper intestinal digestion, perhaps as a result of poor abomasal clotting, and subsequently fermenting to product organic acids in the lower intestinal tract. It is also possible that effects of bicarbonate-containing electrolytes on milk digestion would be more obvious when the two are ingested at closer time intervals; in the present study feedings were at least three hours apart.

Offering milk to calves being fed electrolytes was effective in maintaining body weight. With the exception of the day 6 Life-Guard-treated calves, mean body weight was above prediarrhea values at all times and the calves gained weight by the end of the trial. Maintenance of weight and growth occurred despite the fact that malabsorption of lactose, xylose, and fat has been documented in diarrheic calves (21–23). Our results are, however, consistent with our previous studies which showed that diarrheic calves fed cows' milk gained weight and that milk feeding did not exacerbate diarrhea (12). A considerable reserve digestive capacity exists in the neonatal calf (24) and this is probably why milk can still be adequately digested despite some loss of digestive function. The use of whole cows' milk was also probably beneficial because it has been shown to cause fewer problems than milk replacer in diarrheic calves (25,26). Alternative approaches to nutritional support in chronic diarrhea have been to withdraw milk and either to feed intravenously (27) or to use a high-energy oral electrolyte product (28). However, intravenous feeding is expensive and high-energy products need to be fed three times a day and do not meet the maintenance energy requirements of a 45 kg calf.

In this study calves that failed to respond to electrolyte therapy were removed from the trial and either immediately euthanized or treated with intravenous fluids. Intravenous fluid therapy corrected dehydration and acidosis and all calves improved initially. However, only 33% of calves treated with intravenous fluids maintained this improvement and recovered from diarrhea. All of the calves that were initially in the Ion-Aid group and were treated with intravenous fluids eventually had to be euthanized because of poor body condition and chronic illness. This poor recovery rate cannot be simply ascribed to severe infection because calves treated with a more appropriate electrolyte had much higher recovery rates (92% in the Revibe group). Neither were the losses the immediate effect of dehydration and acidosis, because these problems were corrected with intravenous fluids. It seems possible that, when oral electrolyte therapy fails to maintain homeostasis in diarrheic calves, cellular damage may develop secondary to shock. The development of chronic diarrhea in all of these calves, and septicemia in some, may reflect mucosal damage. The villus mucosa is susceptible to circulatory collapse because the countercurrent exchange mechanism in the villus removes oxygen from the capillaries feeding the villus tip. During low-flow states, even more oxygen is removed and hypoxemia develops at the tip of the villus (29). It is well recognized in dogs that systemic circulatory collapse can induce severe mucosal damage and hemorrhagic diarrhea (30). One of the calves that was euthanized in this experiment had evidence of microthrombosis of the intestinal villi at necropsy. Thus, mucosal damage in the calves may have been the result both of initial viral infection and secondary circulatory failure (31–34). The polyarthritis present in some of these calves when they were euthanized may date from entry of organisms across the damaged gut wall at the time of circulatory collapse. If this hypothesis is correct, it emphasizes the importance of early therapy using an appropriate oral electrolyte. Once a calf on Ion-Aid develops dehydration and persistent acidosis, it is possible to resuscitate it by correcting these imbalances, but damage sustained during the period of circulatory collapse means that the long-term outlook is poor. The two calves that were successfully treated with intravenous fluids were initially assigned to Revibe and Life-Guard treatments and had less severe acidosis than the Ion-Aid calves. Because of the low numbers, it is difficult to know whether or not this is coincidence or whether it reflects a long-term beneficial effect of alkalizing therapy.

In conclusion, Ion-Aid gave very poor results in treating viral diarrhea in our model. Both Life-Guard and Revibe contain alkalizing agents and gave good results.

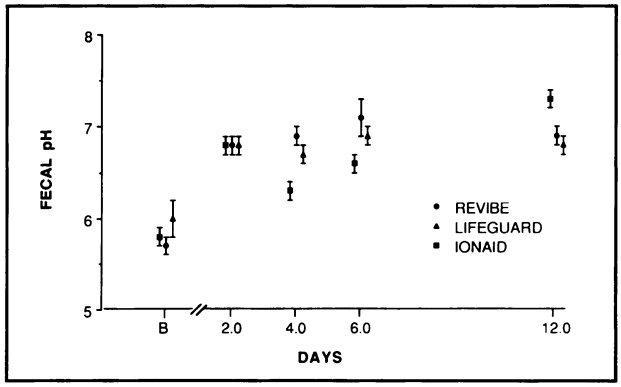

Figure 7. Graph of fecal pH (mean ± 1 SEM) versus time in days. See Figure 5 for details of numbers of calves.

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